Task/Subtask IU00.13
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13 September 1993

# SOFTWARE TECHNOLOGY FOR ADAPTABLE, RELIABLE SYSTEMS (STARS) PROGRAM

## Software Reuse Case Study – TRILLIUM (Final)

Contract No. F19628-88-D-0032
Task IU00 – Program Planning and Infrastructure



Prepared for:

Electronic Systems Center
Air Force Materiel Command, USAF
Hanscom AFB, MA 01731-2816

Prepared by:

IBM Federal Systems Company
800 North Frederick Avenue
Gaithersburg, MD 20879

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS ELECTRONIC SYSTEMS CENTER (AFMC)
HANSCOM AIR FORCE BASE, MASSACHUSETTS

SEP 24 1993

FROM: ESC/ENS
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SUBJ: Distribution Upgrade

TO: IBM Corporation
800 N. Frederick Ave.
Gaithersburg, MD 20879

ATTN: Mr. Dave Ceely

1. Reference IBM letter CLC-0014-93, dated September 15, 1993.

2. The STARS CDRL #05021-002, entitled Software Reuse Case Study: TRILLIUM, is upgraded to Distribution Statement A effective 24 Sep 1993.

3. Please direct any questions you may have to Andrew Hodyke, (617) 377-8473.

James A. Henslee

JAMES A. HENSLEE
ESC STARS Program Manager
Systems and Software Design Center

## DISTRIBUTION STATEMENT UPGRADE

**CDRL Number and Task Number:** IBM CDRL 05021, Task IU00.13

**Product Title and Brief Description (what it is, and what it does):** Software Reuse Case Study: TRILLIUM

This study provides a commercial example in which software reuse is specifically gauged and encouraged as a means to improve quality, timeliness and life-cycle cost. TRILLIUM's recommended software reuse practices are based upon over ten years of successful experience. Reuse is not isolated, but viewed as one of several activities, all of which are needed to ensure software capability. Further, evidence suggests that TRILLIUM has been widely adopted by managers and practitioners throughout Bell's supplier organizations (who have chosen to market TRILLIUM to their customers). As such, this example appears to provide the right goals, long-term experience base and successful approach for getting effective software reuse into practice.

**Date Delivered to the Program Office:** 16 Sep 93

**Reviewer's Name, Extension Number and Date of Review:** Marcelle Hajjar, x4918, 24 Sep 93

**Intended Audience:** Public at conferences, trade shows and workshops

**Comments:**

The STARS product, Software Reuse Case Study: TRILLIUM, previously under Distribution Statement C, is upgraded to Distribution Statement A effective 24 Sep 93. This product is generic and does not apply to specific defense articles and defense services. In accordance with Memorandum of Agreement between ESC/PA and ESC/ENS concerning upgrades of STARS products to Distribution A, the STARS program office at ESC/ENS has reviewed this product and has determined that the information is unclassified, technically accurate, and suitable for public release.

James A. Henslee
Approving Authority

9/24/93
Date

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CDRL Sequence 05021–002
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DoD has identified software reuse as a central strategy for improving the quality, timeliness and cost efficiency of its weapons, command and control and other automated information systems. However, to reap full benefits from software reuse technology, DoD must change the way it does business. The question is how.

This study provides a commerical example in which software reuse is specifically gauged and encouraged as a means to improve quality, timeliness and life-cycle cost. TRILLIUM's recommended software reuse practices are based upon over ten years of successful experience. Reuse is not isolated, but viewed as one of several activities, all of which are needed to ensure software capability. Further, evidence suggests that TRILLIUM has been widely adopted by managers and practitioners throughout Bell's supplier organizations (who have chosen to market TRILLIUM to their customers). As such, this example appears to provide the right goals, long-term experience base and successful approach for getting effective software reuse into practice.

While there are clear differences between DoD and Bell, we believe that the experiences and lessons learned by Bell and its suppliers can provide perspective and insights to those who develop and implement DoD policy.

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Applied Expertise, Inc.

# TRILLIUM

## CASE STUDY

*A Commercial Example of a Software Supplier Capability Assessment Model that Encourages Effective Software Reuse*

**ANNOTATED BRIEFING**

IBM Purchase Order N. 469508
**FINAL**

September 13, 1993

Applied Expertise, Inc.
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# Executive Summary

## PROBLEM

According to the U.S. General Accounting Office, the U.S. Department of Defense (DoD) annually spends over $24 billion to maintain and develop software for its weapons, command and control, and other automated information systems. DoD sees software reuse as a means for better managing these costs and increasing the quality of the software products it acquires and maintains. However, DoD efforts to encourage its suppliers to adopt software reuse have met with a number of acquisition-related barriers. Issues that need to be resolved to alleviate these barriers include:

- ensuring that suppliers will apply reuse to reduce cost and increase quality and timeliness
- determining the extent of supplier capability to effectively apply reuse technology
- avoiding the use of specifications that impose non-essential or counterproductive requirements on customers and suppliers
- achieving "grass roots" support from the acquisition and vendor communities

## INTRODUCTION

To gain insights, DoD's Advanced Research Projects Agency (ARPA) Software Technology for Adaptable Reliable Systems (STARS) program funded a case study of Bell Canada's (Bell) efforts to improve software quality through a joint effort with its principal suppliers. Bell is the largest Canadian supplier of telecommunication services, securing about sixty percent of the Canadian market. Bell provides voice, data, and image services, and the management and operating systems required to sustain them. These services are based on technologies primarily provided by Northern Telecom (NT) and its research and development arm, Bell Northern Research (BNR).

Bell is a commercial organization that acquires software for systems that resemble those of DoD. For example, Bell's

- end-to-end service depends on software systems that are large, critical, complex and subject to rapid changes
- major switching systems contain more than 10 million lines of code, each with a different combination of features
- requirements expand continuously — twice-yearly updates can contain up to 400 new features, each with about 5,000 lines of code
- updates must not impact availability — systems must be available all but two hours in 40 years of operation

## WHAT IS *TRILLIUM*?

Bell's software capability improvement model and methodology ***(TRILLIUM)*** includes software reuse as a significant evaluative factor. ***TRILLIUM*** incorporates software reuse into a framework that stresses improving supplier responsiveness, increasing quality and reducing cost. ***TRILLIUM***, which was developed jointly with Bell's principal suppliers, NT and BNR, adapts DoD's Capability Maturity Model (CMM) to a commercial setting by adding a strong customer focus, a product perspective and technological maturity.

***TRILLIUM*** incorporates quality management practices, industry standards (such as ISO 9000), and requires the involvement of the customer, who adds specific requirements to each assessment. Like the CMM, the ***TRILLIUM*** model consists of a series of levels which represent an organization's software development maturity. At each level there are key work practices which must be enacted to advance to the next capability maturity level.

## OBJECTIVES, SCOPE AND METHODOLOGY

The objectives of this case study are to: (i) determine the process and rationale that led Bell Canada, Northern Telecom, and Bell Northern Research to require and include reuse in their criteria for evaluating software capability; (ii) gauge the level of internal and external support for including reuse as a critical criterion in Bell Canada's software supplier quality evaluations; (iii) discern the impact of ***TRILLIUM*** and its associated reuse practices; and (iv) describe similarities and differences between Bell Canada and DoD in purchasing and developing software products.

This case study was prepared by Applied Expertise, Inc. for DoD's ARPA/STARS program under a sub-contract to IBM Federal Systems Company. The study is the product of three months of research, including on-site visits and face-to-face interviews with the developers and implementors of Bell's software capability improvement model. We caution that information used in the preparation of the case study was acquired primarily from individuals directly responsible for the development and implementation of ***TRILLIUM***.

## STUDY RESULTS

### *TRILLIUM* SOFTWARE REUSE PRACTICES ARE BASED ON LONG-TERM, IN HOUSE EXPERIENCE.

Reuse has long been a part of software development within the tri-corporate organizations (Bell, NT and BNR). Over fifteen years ago, Bell suppliers, NT and BNR, created a product-line architecture, development process and development environment to field quality products within reasonable cost constraints for digital switching systems and to meet customer demands for continuous system upgrades. According to Neil Gammage, Director of Synergy Architecture for BNR:

> *"The only way to make order of magnitude improvements in software quality and developer productivity is to write less code — to reuse."*

According to corporate managers, digital switching system size, complexity, domain stability, and long product life-cycles enabled them to recover the added costs associated with these reuse practices.

The effectiveness of this approach is demonstrated by the fact that only minor changes to the architecture were required for over fifteen years. During this time, NT regularly added hundreds of new features, expanded into international markets, and experienced significant increases in revenues. For example, NT's sales grew from less than $1 billion in 1985 to over $8.4 billion in 1992, largely due to their ability to adapt digital signal processing technologies to new markets.

Recently, however, a rapidly expanding customer base, a continuous demand for new features and the requirements of new technologies have outstripped the response capability of the switching system architecture, process and tools. In July 1993, NT announced a second quarter 1993 loss of $US 1.03 billion. The loss included charges for an aggressive software re-engineering and technology initiatives, proposed to senior management several years ago. Improving software reuse is a key element in this new initiative.

### A COMMITMENT TO CONTINUOUS QUALITY IMPROVEMENT IS A KEY SUCCESS FACTOR FOR BOTH *TRILLIUM* AND REUSE.

Interviewees stressed that effective software reuse cannot be achieved in isolation. ***TRILLIUM*** places reuse as one of a number of development practices that are necessary to ensure an organization's improved software capability. ***TRILLIUM*** defines capability as "the ability of a development organization to deliver a software product that meets customer expectations with minimal defects for the lowest life-cycle cost, in the shortest calendar time." Similarly, close partnership between customer and supplier is cited as an important success factor.

### REUSE WITHOUT APPROPRIATE MANAGEMENT IS INEFFICIENT AND RISKY.

Uncontrolled "cloning" can be hazardous. In 1990, Bell discovered evidence that uncontrolled cloning [reuse], was far more prevalent than expected. While analyzing a large segment of Bell code, Bell managers

were surprised to find numerous modules with the same name and slightly different code, and others with identical code and slightly different names. Though the program still worked properly, the design inefficiency and potential for serious problems with bugs were clear.

Use of libraries without process and infrastructure risks systematic software flaws. Bell's Jean Normand Drouin, who has conducted over fifteen ***TRILLIUM*** supplier evaluations and assessments, stated that most supplier organizations have reuse libraries. Sometimes, however, they do not adhere to a process that tracks and maintains the library's components. Without this process, even more uncontrolled cloning can result.

THE IMPACT OF ***TRILLIUM*** AND ITS REUSE CRITERIA IS PROMISING.

Francois Coallier, Bell's Associate Director of Quality Engineering and Research, stated that while it is too early to measure conclusively, participants in initial pilots appear to be more user-focused, responsive to customer needs, and products are generally more stable. NT and BNR managers stated that they view ***TRILLIUM*** as a means to achieving aggressive corporate goals. This enthusiasm is supported by the fact that NT has trained over 90 in-house, customer and supplier staff, and that tri-corporate managers and practitioners at all levels reportedly support the program.

***TRILLIUM*** use is also expanding to tri-corporate external suppliers, government organizations and international standards groups. For example, ***TRILLIUM*** has been adopted by the French Ministry of Defense, and is strongly shaping the new International Standards Organization SPICE (Software Process Improvement and Capability dEtermination) standard.

BOTH SIMILARITIES AND DIFFERENCES BETWEEN BELL AND DOD PROVIDE PERSPECTIVE.

Bell and DoD require large, complex systems with similar reliability standards and real-time response requirements. Like Bell's systems, many new DoD systems are written in a common, modular, high-order language. In the telecommunications industry and in defense systems, many products have well-defined domains and long life cycles. These characteristics promote effective reuse practices such as those found in ***TRILLIUM***. Further, Bell and DoD suppliers are, to a degree, similarly motivated by the predominant influence of their largest customers.

Despite the influence that they can exercise over their suppliers, there are technical, regulatory, and organizational differences between Bell and DoD. For example, the relationships between tri-corporate organizations (customers and suppliers) are much closer than those between DoD and its contractors, which tend to be more formal. Where suppliers often build one-of-a-kind systems for DoD, Bell supplier NT builds systems to Bell's requirements, then resells them to thousands of customers worldwide.

## SUMMARY

DoD has identified software reuse as a central strategy for improving the quality, timeliness and cost efficiency of its weapons, command and control and other automated information systems. However, to reap full benefits from software reuse technology, DoD must change the way it does business. The question is how.

Experience has shown that simply asking for reuse in a DoD Request for Proposal (RFP) can result in more documentation, higher costs and no benefits. Wrong policy or direction can work against contracts that try to save DoD money or increase product quality or timeliness. Emphasizing software reuse alone, without supporting technology and mature processes, can produce many lines of useless or even hazardous software.

This study provides a commercial example in which software reuse is specifically gauged and encouraged as a means to improve quality, timeliness and life-cycle cost. ***TRILLIUM's*** recommended software reuse practices are based upon over ten years of successful experience. Reuse is not isolated, but viewed as one of several activities, all of which are needed to ensure software capability. Further, evidence suggests that ***TRILLIUM*** has been widely adopted by managers and practitioners throughout Bell's supplier organizations (who have chosen to market ***TRILLIUM*** to their customers). As such, this example appears to provide the right goals, long-term experience base and successful approach for getting effective software reuse into practice.

While there are clear differences between DoD and Bell, we believe that the experiences and lessons learned by Bell and its suppliers can provide perspective and insights to those who develop and implement DoD policy. The ***TRILLIUM*** case study aims to convey these points.

*For more information on the case study, contact David M. Dikel, Principal Author, at Applied Expertise, Inc., 1925 N. Lynn Street, Suite 802, Arlington, VA, 22209, (703) 516-0911.*

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- INTRODUCTION
- SCOPE AND METHODOLOGY
- BACKGROUND
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- CONCLUSION

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## Introduction

- Problem statement
- STARS-funded Approach
- Why *TRILLIUM*?
- Purpose and Objectives

Slide 2

NOTES:

The ***TRILLIUM*** case study provides a commercial example of a software supplier capability assessment model that encourages effective reuse. The study is structured to introduce the reader to the purpose and objectives of the study; define the scope and methodology used by case study evaluators; provide background on Bell Canada (Bell) and ***TRILLIUM***; describe the study results; and offer our conclusions. The study is presented in the form of an annotated briefing. It was prepared as a research product by Applied Expertise, Inc., in accordance with IBM and DoD requirements. For further information on the study, contact David M. Dikel, principal author, at (703) 516-0911.

## Problem Statement

***DoD sees software reuse as a solution. Acquisition-related barriers stand in the way. Issues include:***

- **Ensuring that suppliers apply reuse to achieve DoD objectives, e.g., reduce cost**
- **Evaluating supplier capability to deliver on proposed reuse objectives**
- **Avoiding non-essential or counterproductive requirements, policies, regulations, procedures**
- **Achieving "grass roots" support from the acquisition and vendor communities**

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NOTES:

*The Department of Defense (DoD) estimates that expenditures for developing and maintaining software for its weapons, command and control, and other automated information systems currently exceed $24 billion dollars a year. In an attempt to better manage these costs and improve its ability to develop and maintain high-quality software, Defense has initiated a comprehensive effort to incorporate software reuse practices into its software development efforts.*

**— U.S. GAO, "Software Reuse: Major Issues Need To Be Resolved Before Benefits Can Be Achieved"[1]**

United States Department of Defense (DoD) efforts to encourage effective software reuse[2] from its suppliers have met with a number of acquisition-related barriers. Issues that need to be resolved to alleviate these barriers include[3]:

- ensuring that suppliers will apply reuse to reduce cost, increase quality and timeliness
- evaluating supplier capability to effectively apply reuse technology and deliver on proposed reuse objectives
- avoiding the use of specifications that impose non-essential or counterproductive requirements, policies, regulations and procedures on customers and suppliers
- achieving "grass roots" support from the acquisition and vendor communities

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1 U.S. General Accounting Office, "Software Reuse: Major Issues Need to Be Resolved Before Benefits Can Be Achieved," January 1993, p. 1.

2 The DoD defines reuse as, "The application of a reusable [software] component to more than one application system." (Department of Defense, "Software Reuse Initiative: Vision and Strategy," July 15, 1992, 1st edition, p. 2.) Reuse can occur within a system, such as within a robot arm; across similar systems, like a product line of household appliances; or in common services for widely different systems, for example, user interface tools. Any product created during the software development life-cycle is considered a component, and a potential resource for reuse.

3. The case study does not seek to address all of the acquisition-related barriers, such as data rights issues, for example. In this regard, this list is not intended to be totally inclusive. The list includes issues raised during joint meetings of the DoD Management Issues Working Group and ACM/SIGAda Reuse Acquisition Action Team, as well as during interviews with our case study review team, a group that represents the concerns of DoD and NASA policymakers, Program Executive Officers, Program Managers and senior technical managers from the defense/aerospace community.

## STARS-funded Approach

***The TRILLIUM Case Study looks at getting effective reuse into practice***

- **From the perspective of the customer**
- **As part of an overall quality initiative**

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NOTES:

This illustrative case study was prepared for DoD's Advanced Research Project Agency (ARPA) Software Technology for Adaptable Reliable Systems (STARS) program to provide insights and suggest strategies towards the resolution of these issues. The study was authorized under a sub-contract to IBM Federal Systems Company. The study focused on the joint effort of Bell Canada, Northern Telecom and Bell Northern Research to produce a software product development capability evaluation model called ***TRILLIUM***. The aim of the case study is to examine Bell Canada's efforts to promote effective supplier participation in key technologies — in this case, software reuse — to increase their software capability in the context of an overall quality initiative. ***TRILLIUM*** is a self-assessment tool which includes software reuse as a significant evaluative factor. It allows continual improvement of software processes through self-assessment.

## Why *TRILLIUM*? (1 of 2)

***Bell Canada system requirements resemble those of DoD***

***End-to-end service depends on software systems that are large, critical, complex and subject to rapid changes***

**Digital switch characteristics**

- **System size: >10 MLOC (million lines of code)**
- **Almost every installation has a different feature set**

  **->2,400 installations worldwide**
- **Continuous demand for new features:**

  **-- Typical update**

  - **has 400 features, each with about 5,000 LOC**
  - **represents efforts of 1,200 s/w designers**
- **Updates must not impact availability**

  **< 2 hours downtime in 40 years**

***Do not use these data to calculate productivity***

Slide 5

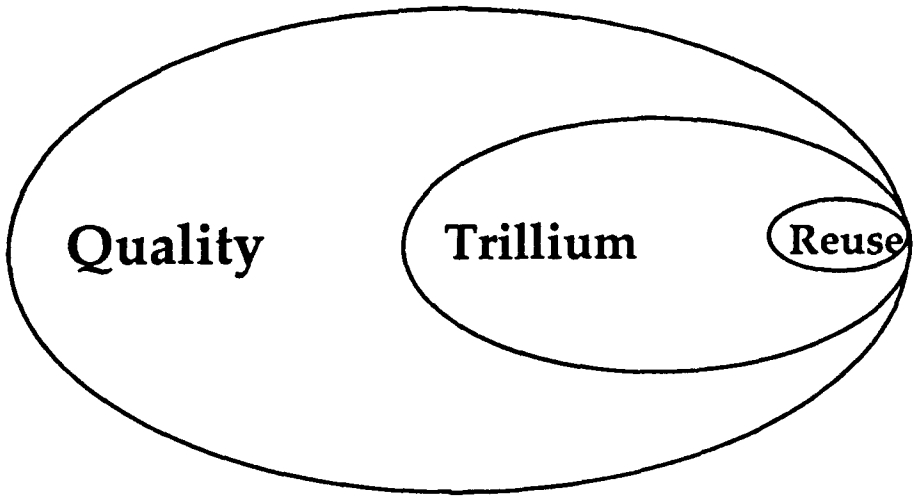
NOTES:

Northern Telecom's DMS series, which is a product line of digital switching systems, performs a broad range of telecommunications applications, including toll, local and international services in over 2,400 installations worldwide (1989). Each installation requires a unique combination of product features.

NT develops new features for regularly scheduled release to meet aggressive customer demand. A typical release of software has 400 features, each using an average of 5,000 lines of code. Each release represents the collective efforts of some 1,200 software designers located in the U.S., Canada and the U.K. Releases must be installed quickly, while maintaining system reliability requirements of less than two hours downtime over a 40 year period of operation.

## Why *TRILLIUM*? (2 of 2)

***Bell incorporated s/w reuse practices into a framework that***




- **Stresses improving supplier responsiveness, increasing quality and reducing cost**
- **Enjoys the committed support of senior managers within Bell Canada, Northern Telecom and Bell Northern Research**
- **Involves participation from all practitioners and managers (customer and supplier)**
- **Is central to a Total Quality Management (TQM) program**

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NOTES:

The ***TRILLIUM*** model expands the Software Engineering Institute's Capability Maturity Model (SEI/CMM) to include a strong customer focus, a product perspective, technological maturity and software reuse. The model consists of a series of levels which represent an organization's software development maturity. At each level there are key work practices which must be enacted to advance to the next level. ***TRILLIUM*** incorporates quality management practices, a number of industry standards as benchmarks for assessments, and specific customer requirements for each assessment.[4] Software reuse practices exist at levels two and beyond (for a detailed outline of these practices, see the index to ***TRILLIUM***, attached as appendix V). Most of these reuse practices are original to ***TRILLIUM*** and are not based on the CMM, IEEE standards, or other inputs to the model.

***TRILLIUM*** supports an assessment methodology and a questionnaire that can be used jointly by customer and supplier in self-assessment mode, or alternately by the customer in audit mode. ***TRILLIUM*** self-assessments enable the supplier to openly identify areas that need improvement in the presence of the customer; as such, self-

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4 The authors of the model stressed that TRILLIUM standards and evaluation criteria are not immutable. They are provided as a framework to assess the software development process and are meant to encourage continuous improvement.

assessments require and hopefully foster a significant level of trust between customer and supplier. According to Bell managers, self-assessments can provide customers strong assurance that suppliers are: (i) committed to continuous quality improvements, (ii) aware of key areas that need improvement, and (iii) taking aggressive and specific actions to improve. In assessment mode, a team of evaluators consists of members of the supplier organization and at least one member of the customer organization. The team uses the ***TRILLIUM*** questionnaire and interviews project managers and product users to identify weaknesses in the development process. These weaknesses are then addressed in an effort to increase product quality and reduce costs.

In audit mode, customers use the model as a standard by which to choose among potential suppliers, or as a tool to analyze and remedy serious cost/schedule/quality problems with current suppliers. Bell chooses between these options based on supplier performance and the criticality of supplier software products. ***TRILLIUM*** incorporates national and international standards into its assessments.

## Purpose and Objectives

- **Determine the process and rationale for *TRILLIUM* reuse criteria**
- **Gauge internal and external support for these criteria**
- **Discern the impact of *TRILLIUM* and its reuse practices**
- **Describe similarities and differences between Bell Canada and DoD**

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NOTES:

The ***TRILLIUM*** case study was prepared for DoD officials to provide insights and suggest strategies towards breaking down acquisition-related barriers to effective software reuse.

The objectives of the case study were to:

- Determine the process and rationale that led Bell Canada, Northern Telecom, and Bell Northern Research to require and include reuse in their criteria for evaluating software capability.
- Gauge the level of internal and external support for including reuse as a critical criterion in Bell Canada's software supplier quality evaluations.
- Discern the impact of ***TRILLIUM*** and its associated reuse practices.
- Describe similarities and differences between Bell Canada and DoD in purchasing and developing software products.

# Scope and Methodology

*Effort – about three person months including*

- **Interviews with Case Study Review Team**
- **Site visits to Bell, BNR and Ecole Polytechnique**
- **Additional face-to-face interviews at IEEE / Quality Management Assurance Committee (QMAC) Workshop**
- **Collection and review of documents from tricorp managers, industry journals, annual reports, SEI, etc.**

*Coverage*

- **3 of 3 *TRILLIUM* principal authors**
- **2 of 6 initial *TRILLIUM* implementors**
- **BNR Software Reuse Program Manager**
- **Corroborating interviews at several levels of each tri-corporate organization**

*Caveats*

- **Most subjects had a stake in *TRILLIUM***
- **Do not use data to estimate productivity — counts of lines of code/programmers are provided for comparisons only**
  - **BNR mgr. noted that the # of programmers can vary by an order of magnitude, "depending on how you count"**

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NOTES:

Field work for the case study was accomplished during the period May through July of 1993. A fact sheet was provided to tri-corporate managers for comments. In addition, an annotated briefing was held for selected reviewers of the case study in August 1993 (see Appendix II for list and titles of reviewers). Where appropriate and necessary, comments received from tri-corporate managers and reviewers were considered in the preparation of the final case study.

We reviewed and analyzed documents and materials related to the development and application of ***TRILLIUM***; held interviews in Montreal and Ottawa with managers and technologists of Bell Canada, Northern Telecom and Bell Northern Research; and interviewed the Program Manager for industry software development projects at Ecole Polytechnique in Montreal, whose group develops and supplies case tools to Bell. In order to develop a broader perspective on ***TRILLIUM***, information was obtained from different levels (customer and supplier) of the tri-corporate structure. We also conducted face-to-face interviews at a telecommunications quality management workshop (the IEEE/QMAC workshop), where we gathered background information from Bell suppliers and heard presentations on uses of capability maturity models within the telecommunications industry.

The information used in the preparation of the case study was acquired primarily from individuals directly responsible for the development and implementation of ***TRILLIUM***. We spoke with each of ***TRILLIUM***'s three principal authors, two out of six of its initial implementors, and the BNR Software Reuse Program Manager. We also conducted corroborating interviews at several levels of each tri-corporate organization.

These individuals have an investment and vested interest in the success of ***TRILLIUM*** within the tri-corporate structure and as part of their commitment to quality management. Nevertheless, the corroboration of information from different corporate levels and elements of the tri-corporate structure provides reasonable assurance that the information obtained is reliable. In this regard, to the extent practical, the case study attributes the information to its source.

# Background

- **Tri-corporate Relationships**
- **Quality, *TRILLIUM* and Reuse**
- ***TRILLIUM* History and Implementation**

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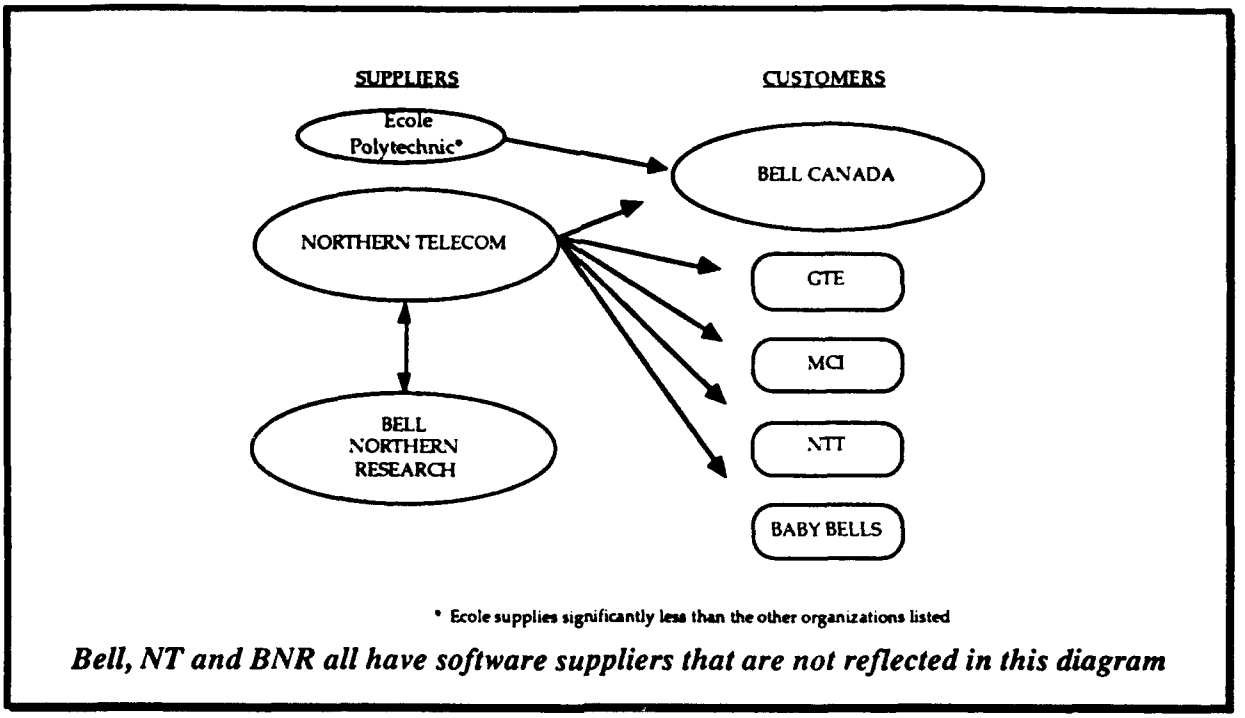
NOTES:

The Background section is intended to provide perspective to the reader by describing customer-supplier relationships, their commitment to quality, and the history and implementation of ***TRILLIUM***.

## Tri-corporate Relationships




Slide 10

NOTES:

The tri-corporate family consists of Bell Canada (Bell), Northern Telecom (NT) and Bell Northern Research (BNR), which are owned wholly or in part by the parent holding company, BCE, Inc.[5]. Bell is the largest Canadian supplier of telecommunications services, securing approximately sixty percent of the Canadian market. It provides voice, data and image services, and the management and operating systems required to sustain them. These services are based on technologies primarily provided by NT and BNR.

NT's digital switches are at the heart of Bell's systems, and NT supplies more than two thirds of Bell's total software purchases. NT, in turn, relies on BNR, its R&D subsidiary, for the software required to develop its switching and transmissions systems.[6] BNR's pioneering innovations in digital telecommunications systems has made NT the world's largest supplier of digital switches. According to Al Graydon, Manager of Software Excellence at NT, in 1985 the company had less than $US 1 billion. In 1992 it posted sales in excess of $8.4 billion. This growth was mainly due to the competitive advantage from implementing digital signal processing technologies before competitors. Quality initiatives provided through ***TRILLIUM*** are viewed as key to sustaining growth.

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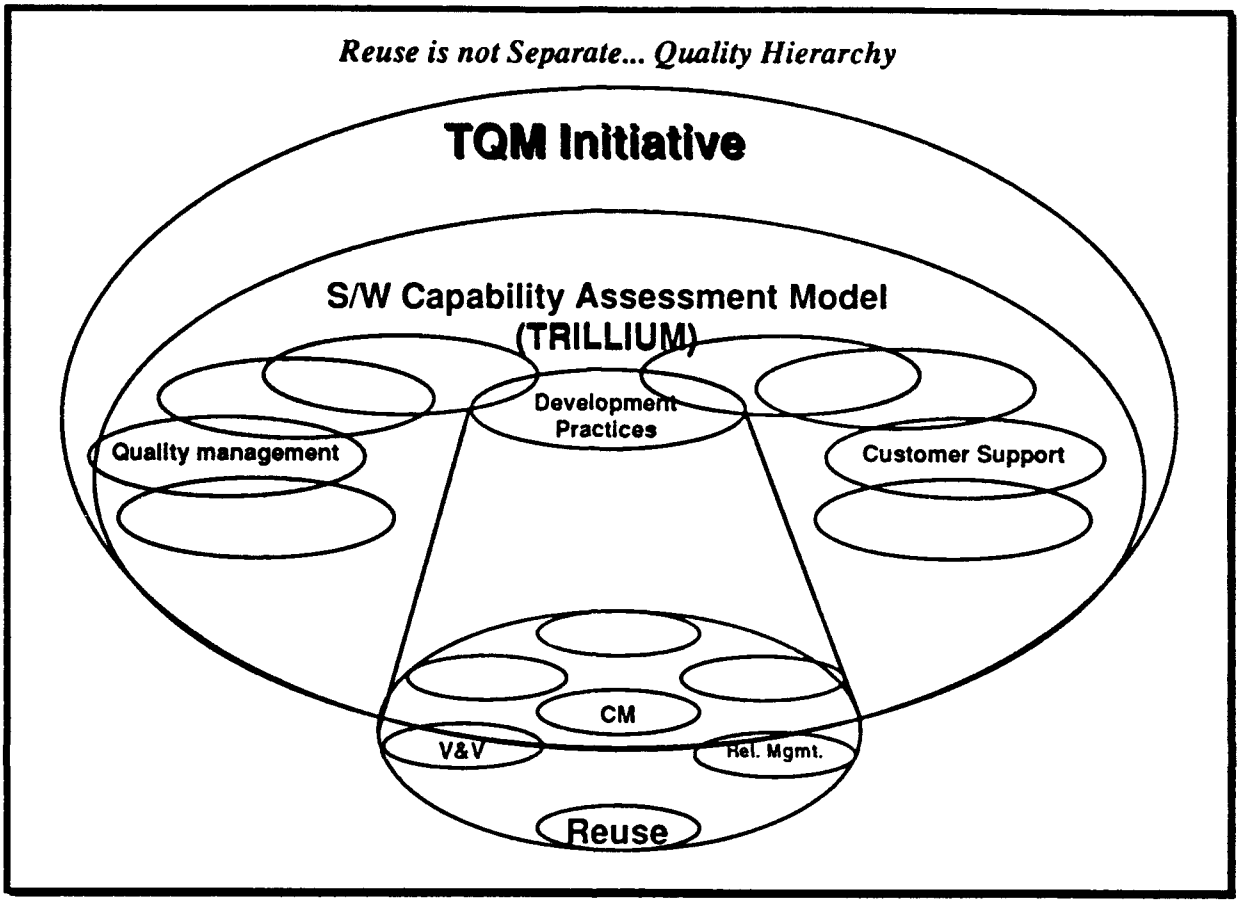
5 BCE, Inc. owns 100% of Bell 52.7% of NT, and 100% of BNR through Bell and NT. Bell owns a 30% share of BNR, and NT is the majority owner with 70%.

6 BNR produces 99% of NT's software and receives 90% to 95% of their funding from NT.

## Quality, *TRILLIUM* and Reuse

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NOTES:

Interviewees stressed that effective software reuse cannot be achieved in isolation. ***TRILLIUM*** places reuse as one of several important development practices. In this context, reuse success is tied to an organization's overall software capability and its commitment to continuous quality improvement.

The ***TRILLIUM*** model defines capability in this context as, "The ability of a development organization to deliver a software product that meets customer expectations with minimal defects, for the lowest life-cycle cost, in the shortest calendar time."[7] The ***TRILLIUM*** model is comprised of nine capability areas, ranging from quality management to customer support to development practices. Included within seven development practices are: configuration management (CM), verification and validation (V&V), reliability management, and software reuse (see Appendix V).

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7 Bell Canada Document, "Trillium: Telecom Software Product Development Capability Assessment Model," July 1992, Draft 2.2, p. 2.

## *TRILLIUM* History

- **Foundation document presented to ASQC Conference by Francois Coallier [July '91]**
- **Tri-corporate team formed [October '91]**
- **Five self-assessments conducted [April '92 - April '93]**
- **Fiber Systems self-assessment [April '92]**
  - **Fiber Systems builds four products requiring**
    - **> 3 MLOC each**
    - **about 2,000 programmers**
- **> 15 assessments and audits of Bell's external suppliers**

***Do not use these data to calculate productivity***

Slide 12

NOTES:

***TRILLIUM*** was developed from a tri-corporate joint effort to assess and enhance NT's and BNR's software development processes. After conducting manufacturing audits for many years, Bell decided that it was necessary to analyze supplier software development. Around 1982, Bell began auditing NT's software using IEEE standards [e.g. IEEE 730]. By 1988 these audits started to look at supplier capability using a simple questionnaire in conjunction with the IEEE standards. This change in approach resulted from concerns with supplier performance, life-cycle costing and product reliability in light of the rapid growth in system size and complexity. At this point, Bell also began to fund academic and BNR research into solutions to these issues.

These audits were concomitant with NT's introduction of "Excellence," a TQM program which would play a key role in ***TRILLIUM*** implementation. This program quickly moved into BNR and was in full gear in both organizations by 1990. Further setting the stage for ***TRILLIUM*** was the 1989 consolidation of responsibilities under one director for all aspects of quality (e.g., hardware and software). This increased the leverage of the software quality initiative, since it represented a high priority for Bell's continuous quality assurance process.

In 1990, Bell began to look at a comprehensive approach to ensuring quality in the software development process. Al Graydon, NT's Manager of Software Excellence, stated that at this time, Bell approached BNR and NT with the prospect of expanding the scope of software audits to the level of detail found in manufacturing. NT and BNR felt, however, that traditional audits were not the best method of approaching the task. A tri-corporate team was formed to look into other evaluation methods. The fourteen-member tri-corporate team was headed by Neil Gammage, then Program Director for the Software Engineering Centre at BNR, Francois Coallier, Associate Director of Quality Engineering and Research at Bell, and Al Graydon. The objective was to create a model which would take the best of existing evaluation methods and combine them into a unified whole.

***TRILLIUM*** was first tested as an evaluative tool at BNR in the summer of 1991. The first self-assessment, led by Don Joyce, Manager of Transmission Development Processes, was conducted at Fiber Systems in 1992. Fiber Systems now builds several systems that contain over 3 MLOC each and involve about 2,000 programmers, according to Joyce. Joyce was introduced to what became ***TRILLIUM*** in late 1991 and helped to promote the methodology to BNR upper management and throughout the organization. The first draft of what became ***TRILLIUM*** was published in July of 1991 and was presented by Coallier at the First Annual American Society for Quality Control (ASQC) Software Conference in October 1991.

Since the first BNR self-assessment, ***TRILLIUM*** has spread throughout NT and its supplier base. To date, five full assessments and numerous Bell audits have been completed. ***TRILLIUM*** has evolved to reflect the acquired knowledge from the assessments and has been fully integrated into the overall quality improvement efforts within the tri-corporate organizations.

# Results

- ***TRILLIUM*** **criteria were intended to improve and expand on existing Tri-corporate software reuse practices**
- ***TRILLIUM*** **and its reuse criteria enjoy strong support in Tri-corporate organizations**
- **The impact of *TRILLIUM* and its software reuse criteria looks promising**
- **Similarities and differences with DoD provide perspective**

Slide 13

NOTES:

During our research, we found several examples that we believe demonstrate competitive advantage gained from effective software reuse. One such example, BNR switching systems, is discussed in this study. Switching systems provided a long-term experience base upon which *TRILLIUM*'s reuse criteria were formed. We found widespread support for these practices and some evidence of impact. We also identified similarities and differences between Bell and DoD which need to be considered. The following annotated briefing charts describe the results of our study.

## *TRILLIUM* Criteria Intended to Improve and Expand on Existing Reuse Practices (1 of 4)

***Bell System Characteristics and Competitive Pressures Engendered Reuse***

- **Updates: 2 MLOC every six months**
- **Updates must not impact availability**
- **Hundreds of configurations — almost every installation has a different set of features**

*For Bell, new features mean increased revenues and staying ahead of competition*

*For Northern Telecom, new features mean market share*

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NOTES:

***TRILLIUM*** CRITERIA SOUGHT TO IMPROVE AND EXPAND ON EXISTING TRI-CORPORATE REUSE PRACTICES

Reuse has long been a part of software development in tri-corporate organizations. For example, over fifteen years ago, Bell suppliers, NT and BNR, created a product architecture and reuse library to develop quality products within reasonable cost constraints for digital switching systems. For other products, however, reuse practices were not nearly as advanced. Design architecture was uneven throughout tri-corporate systems and some reuse took the risky form of unmanaged cloning.[8]

In an effort to address this situation, tri-corporate managers looked at successful systems which, because of their size and complexity, stable well-defined domains and long life cycles, had engendered effective reuse practices. These systems were used to formulate a set of "best practices," many of which were incorporated into ***TRILLIUM*** to provide structure and management to existing software reuse practices, and to expand the scope of reuse throughout tri-corporate systems.

Bell System Characteristics and Competitive Pressures Engendered Reuse

NT/BNR digital switching systems provide an example of systems that have benefited from reuse. Reuse practices were developed to meet customer demands for continuous system upgrades. Reuse was feasible because system characteristics enabled developers to recover the added initial costs associated with these practices.

DMS systems perform a broad range of telecommunications applications, including toll, local and international services in over two thousand four hundred (2,400) installations worldwide (1989).

Each installation requires a unique combination of product features.

NT develops new features for release every six months to meet aggressive customer demand. A typical release of software has four hundred features, each using an average of five thousand (5,000) lines of code. That is, two million (2M) lines of new code are

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8 Interviewee definitions of cloning ranged from copying a major software product and modifying one or more modules, to copying a small module with little or no modification.

produced and implemented every six months. Each release represents the collective efforts of some twelve hundred (1,200) software designers located in the U.S., Canada and the U.K. Releases must be installed quickly while achieving system reliability requirements which limit downtime to less than two hours over a forty year period of operation.

Reuse was the natural reaction to these stringent requirements. As stated by Neil Gammage, Director of Synergy Architecture at BNR:

> *"The only way to make order of magnitude improvements in software quality and developer productivity is to write less code — to reuse."*

NT and BNR reuse practices evolved to meet the challenges inherent in developing these systems.

## *TRILLIUM* Criteria Intended to Improve and Expand on Existing Reuse Practices (2 of 4)

***Reuse Involved Architecture, Processes and Tools***

- **Product-line architecture went virtually without change for 15 years**
- **Distributed Product Library**
  - **controls over 100 libraries of software, firmware, hardware and documentation and enforces process**
  - **supports fifteen different releases**
  - **entire product line generated >20 MLOC**
- **Product Tracking System tracks individual features, test cases and problem reports**
- **High level programming language uniformity supports modularity and information hiding**

Slide 15

NOTES:

Reuse Involved Architecture, Processes and Tools

To manage and control the systems described above, BNR developed product architectures, a set of sophisticated tools, and a carefully controlled process. Modular architecture for both hardware and software was developed to allow efficient expansion and upgrading of individual systems in excess of ten million (10M) lines of code, without disturbing system operations. A central library evolved, from which all systems are currently generated. This resource presently contains more than twenty million (20M) lines of source code.

Because switching systems architecture was well designed in the initial stages, it has needed only minor changes to support changes in technology during its initial twelve years. As a result, NT has been able to evolve its existing switch base rather than replace it. This architecture enabled NT to offer customers the ability to select only features they required, while its competition offered only a few variations. This "evergreen" capability has been a key factor in NT's success with these systems, and in turn, the telecommunications services provided by Bell. Recently, however, the requirements of new technology and expanded customer demands have outstripped the capability of system architecture and tools to respond. NT is now in the process of implementing several aggressive initiatives designed to meet these demands. Software reuse is a key element in this new approach. (See following section for more detail.)

Tools and processes helped to manage the development environment and control reuse. In 1989 and 1990, BNR's *Telesis* publication described a multi-site integrated "Product Development Environment," consisting of a "Product Library System" and a "Product Tracking System." According to the publication, the Product Library System organizes and manages over one hundred libraries of software, firmware, hardware and documentation. It stores and manages the product's source files, including code, documentation, and data. The library system can simultaneously support fifteen different releases of software. The Product Tracking System tracks the progress of

individual features, the development and execution of test cases, and the resolution of internal and external problem reports. According to *Telesis*, the environment "ensures a standard design process and delivery methodology for DMS software across several sites and design groups."[9]

Further, the Product Development Environment's storage and reporting capability "enables the BNR design community and Northern Telecom to know exactly what is in each software release at any time. The environment can instantly tell them, for example, what features have been developed, what problems fixed, the number of test cases executed, and the pass rates on test cases and problem fixes."[10]

Reuse was further promoted by language uniformity in software development projects. Virtually all tri-corporate software is written in a single, proprietary, high-level programming language called PROTEL, which supports programming modularity and information hiding.

*For further information please consult the following sources:*

*Johns, Kalli, "Product Development Environment: Managing large software systems,"* Telesis 1989 three, *BNR, pp. 51-58.*

*Cashin, Peter, "BNR remains at forefront of computing technology,"* Telesis issue no. 92, *pp. 73-75.*

*Stewart, Ian, "From POTS to intelligent services,"* Telesis issue no. 92, *pp. 94-98.*

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9 Johns, Kalli, "Product Development Environment: Managing large software systems," *Telesis 1989 three*, BNR, pp. 53.

10 Ibid.

## Architecture and Environment Maturity is a Double-edged Sword

- **Innovative architecture, process and support system allowed NT to expand into new markets quickly**
  - **Total control of development/target environment (compiler, tools, O/S and hardware)**
  - **Modular architecture allowed rapid tailoring of product**
  - **Approach resulted in exponential code growth**
  - **Several years ago requirements stripped capacity**
- **Lack of ability to leverage advances in COTS technology**
- **New environment and approach proposed — senior management balks at risk**
- **Result: Recently announced problems**

***New architecture, case tools, object-oriented technologies and software reuse, are key elements of NT's solution***

Slide 16

NOTES:

BNR's innovative architecture, process and support system allowed NT to quickly expand into new markets. Complete control over development and target environments, as well as a modular architecture, permitted NT to develop more new features faster than the competition, to respond to thousands of unique combinations of customer requirements, and to adapt to rapid changes in technology. This approach also resulted in exponential code growth and restricted BNR's ability to leverage commercially available off-the-shelf case tools and technologies. In recent years, however, requirements have started to exceed capacity. Recently announced problems by NT reflect this observation.

In July 1993, NT announced a second quarter loss of $US 1.03 billion. It now expects a loss for the full year 1993. According to Jean C. Monty, president and chief executive officer of NT, among the major factors impacting the quarter were declines in gross margins, investments in restructuring and software, and significantly lower Central Office Switching (COS) software sales. According to a BNR manager, much of the decline in software sales is due to a ten-month slippage in the latest software update. While COS revenues declined, product line revenues "showed good growth" in Transmission and Multimedia Communications Systems.[11]

According to *Business Week*, the recent troubles began last year when NT's phone switches required updating. Several U.S. companies experienced problems with the software in NT's phone switches; they complained about the time it took for NT to respond to their demands to fix the glitches.[12] According to *Business Week*, late last year Monty proposed to then-CEO Paul G. Stern a major software revamping and

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11 Northern Telecom news release, "Northern Telecom Announces Second Quarter Results," July 21, 1993.

12 Ziegler, Bart, "What Really Happened at Northern Telecom," *Business Week*, August 9, 1993, p. 27.

simplification. Stern reportedly agreed in principle, but the issue, said Monty, was one of "how much and how fast." Stern considered the software revamping but "could never figure out how to do it" without disrupting operations. The result became the recently announced problems by NT.[13]

NT's board of directors has reacted to current problems by approving special charges for restructuring and a new software initiative. "The investments in restructuring and software are expected to significantly reduce operating costs and enhance the software delivery process to the benefit of our customers and our shareholders," said Monty. "We expect to return to profitability no later than fourth quarter 1993." The restructuring program will cost $US 282 million after tax, and the software initiative $US 158 million after tax. The objective of the latter, according to Monty, is "to generate competitive advantage," including: "best in class quality, significant increases in design productivity, and an improved capability to rapidly deliver customized products to individual customers in diverse global markets." The development is scheduled for completion in 1994, with market rollout slated for 1995.[14]

These problems were identified several years ago by NT and BNR managers. They proposed the following aggressive measures to address them:

- Improving software capability *(TRILLIUM)*
- Redesigning the product architecture
- Adopting object-oriented technology and case tools
- Implementing advanced software reuse techniques

According to an NT manager, NT and BNR took immediate action to develop and adopt a capability assessment model. This action resulted in ***TRILLIUM***. As noted above, additional measures requiring top-level approval are now in progress.

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13 Ibid.

14 News release, op. cit.

## *TRILLIUM* Criteria Intended to Improve and Expand on Existing Reuse Practices (3 of 4)

***TRILLIUM reuse practices were based on long-term, in-house experience***

**Level 1* practices are random, may involve uncontrolled cloning**

**Level 2 and 3 practices were chosen to ensure high return on investment**

- **Level two practices harness and manage "cloning"**
- **Level three practices control, manage and maintain library artifacts**

*** Levels based on a scale of 1 to 5, with level 5 being the highest**

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NOTES:

*TRILLIUM* Reuse Practices Were Based On Long-Term, In-House Experience

NT and BNR gleaned valuable information in developing their switching systems, which were used to create the reuse criteria and technology road map set by ***TRILLIUM***. Specific ***TRILLIUM*** reuse practices were chosen because they brought the highest return on investment, or as Gammage stated it, *"showed the most bang for the buck."* In addition to in-house experience, these criteria also reflect information learned from state of the industry and state of the art practices.

***TRILLIUM*** reuse criteria are characterized as follows. Level one software development is a random process which may involve uncontrolled cloning; level two is basic, managed cloning, requiring documentation and tracking of all modules; and level three requires a carefully controlled library of source code templates and units along with the proper organizational structure to develop, certify, document and maintain the items in the library. At level four and above are advanced reuse practices that are only projections for most organizations involved in software development. Interviewees were not specific as to the extent that they were using level four reuse practices.

## *TRILLIUM* Criteria Intended to Improve and Expand on Existing Reuse Practices (4 of 4)

***Reuse Without Appropriate Management Is Inefficient and Risky***

- **Uncontrolled "cloning" can be hazardous**
- **Use of libraries without process and infrastructure risks systemic software flaws**
- **For Bell, effective development means identifying reuse potential at the design stage**

***"When [the proper] infrastructure does not exist, attempted reuse practices show systemic flaws."***

***— Don Joyce, Manager of Transmission Development Processes***

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NOTES:

Reuse Without Appropriate Management Is Inefficient and Risky

Although recommendations and strategies differed between interviewees, there was consensus that appropriate management of software reuse at all stages of the development process is a very important element of a successful reuse initiative. For tri-corporate managers, appropriate management includes:

- Controlling the cloning process
- Supporting library use with a defined process and infrastructure
- Identifying reuse potential at the design stage

Interviewees stated that architecting products at the design stage to enable reuse during their implementation is equally important. These practices help organizations realize the potential benefits of reuse while mitigating proliferation of bugs in cloned modules.

Prior to ***TRILLIUM***, tri-corporate managers recognized the prevalence of "uncontrolled cloning" and the potential hazards of this practice. One example that brought this to their attention was a code analyzer experiment conducted at Ecole Polytechnique. While studying a large segment of Bell code, Bell managers were surprised to find numerous modules with the same name and slightly different code, and others with identical code and slightly different names. Though the program still worked properly, the design inefficiency and potential for serious problems with bugs were obvious. ***TRILLIUM*** authors created the level two ***TRILLIUM*** criteria to address the issue. According to Don Joyce, Manager of Transmission Development Processes,

*"When [the proper] infrastructure does not exist, attempted reuse practices show systemic flaws."*

Another area on which tri-corporate managers have focused is the appropriate management of reuse libraries. Jean Normand Drouin, who has conducted over fifteen ***TRILLIUM*** supplier evaluations and assessments, has found that most organizations meet level two requirements and many have already implemented reuse libraries. Sometimes, however, they do not adhere to a process that tracks and maintains the

library's components. Without this process, even more uncontrolled cloning can result. He stressed that these organizations must adhere to a library management process to make reuse successful at this level. This includes tracking modules carefully, having ownership of modules reside with one individual, and educating users to make more efficient use of the library. Further, he stated that tools alone will not promote effective reuse.

It was made very clear by interviewees that those who use these libraries should understand and manage the reuse process on the most basic level, or they risk the same dangers as uncontrolled cloning. Moreover, Drouin stated that good development practices should ensure that reuse starts at the design level, where it is most important. Drouin added:

> *"You need to be able to demonstrate at the end of your design how reuse will happen [in the implementation of the design]."*

## *TRILLIUM* and Its Reuse Criteria Enjoy Strong Support

- **Tri-Corporate commitment to quality is a key success factor**
- **Bell's influence also generates support**
- **Assessment criteria need improvement**
- **Supplier support is demonstrated by customer / in-house training**

Slide 19

NOTES:

*TRILLIUM* AND ITS REUSE CRITERIA ENJOY STRONG SUPPORT IN TRI-CORPORATE ORGANIZATIONS

***TRILLIUM*** implementation has been a key objective for Bell, NT and BNR since the program's inception in 1991. Tri-lateral support stems mainly from the "quality culture" fostered by TQM programs in these organizations. Other factors related to this "quality culture" also play a role in generating support for ***TRILLIUM***. These include Bell's partnership approach to supplier relationships, and buy-in to the program by key members of the tri-corporate organizations. In addition to a corporate emphasis on quality, Bell's influence with suppliers plays a role in their endorsement of the model. Because of these factors, *TRILLIUM* is now an integral part of software development at NT and BNR. It has also been implemented by the software development organization at Ecole Polytechnique, a research institution supported by Bell funding and a supplier of CASE tools to Bell.

## *TRILLIUM* and Its Reuse Criteria Enjoy Strong Support (1 of 4)

*Tri-Corporate Commitment to Quality Is a Key Success Factor*

- **Commitment to continuous quality improvement sets context and provides motivation for *TRILLIUM* and reuse**
- **Customer and supplier partnership is paramount**

Slide 20

NOTES:

Tri-Corporate Commitment to Quality Is a Key Success Factor for ***TRILLIUM*** and Reuse

Tri-corporate managers agreed that the key success factor for ***TRILLIUM*** and for reuse is the above mentioned commitment to a continuous quality improvement process. TQM programs are widespread and strongly supported; all management personnel have taken a training program on quality, and everyone in Bell and NT has taken an internal quality training course. In their view, the tri-corporate enthusiasm for ***TRILLIUM*** is directly related to the mindset engendered by these programs.

According to Coallier, supplier maturity is necessary to secure the potential benefits of the exercise. Coallier explained that when a good self-assessment is conducted, gaps and "islands of excellence" in the software development process are identified. A skillful manager will focus on these "islands" quickly and use them to spread excellence throughout the organization. Once the gaps are bridged, the software development process becomes much more efficient.

However, an immature self-assessment imparts few benefits. Coallier told us of a Bell supplier self-assessment outside of the tri-corporate family that was problematic. The organization lacked the maturity to share constructive criticisms of their capabilities and instead sought primarily to achieve the highest possible score on the ***TRILLIUM*** scale. Coallier stated that in doing this, they overlooked significant gaps in their development process, thereby ignoring the ultimate goal of the exercise. In this case, the self-assessment was scrapped and ***TRILLIUM*** had to be used in audit mode.

Tri-corporate managers also stressed that creating a partnership between suppliers and customers is of paramount importance for implementing ***TRILLIUM***. An antagonistic relationship can only be counterproductive and will eventually negate the effectiveness of the model. In addition, they stated that there must be a commitment to ***TRILLIUM*** by key people in the supplier organization who will champion the program and spread it throughout the organization.

## *TRILLIUM* and Its Reuse Criteria Enjoy Strong Support (2 of 4)

***Bell's Influence Also Generates Support***

- **Bell is Northern Telecom's largest customer — $1.3 B / year**
- **Other NT customers look to Bell as a testbed for new products**
- **Bell penalizes suppliers for poor performance**
- **Software/hardware quality and *TRILLIUM* programs under one manager**

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NOTES:

Bell's Influence Also Generates Support for ***TRILLIUM***

Bell suppliers are motivated not only by the potential competitive gains in the global marketplace from using ***TRILLIUM*** and the cultural factors as outlined above, but also by the leverage that Bell wields as their largest and most influential customer. First, NT accounts for about $1.3 billion of Bell's $3 billion per year in total purchases of products and services. Second, Bell often acts as a test-bed for new NT products. As such, we believe that other operating companies look for Bell's acceptance before committing to major purchases. Third, Bell penalizes suppliers for poor performance. In the past, Bell has actively pursued suppliers, forcing them to correct any defects or provide a retrofit at no additional cost. While it would be unfair to characterize these factors as the impetus behind NT's and BNR's acceptance of ***TRILLIUM***, it would also be unrealistic to assume that they carry no weight.

## *TRILLIUM* and Its Reuse Criteria Enjoy Strong Support (3 of 4)

*Assessment Criteria Need Improvement*

- **Evaluative questionnaire is ambiguous in parts, and unduly burdensome**
- **Problems to be resolved in Fall 1993 release**

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NOTES:

Assessment Criteria Need Improvement

While ***TRILLIUM*** implementation has been successful, there are problems with the assessment criteria. Managers at NT, BNR, and other organizations with ***TRILLIUM*** experience have found that some practices required by the evaluative questionnaire are ambiguous, and others are unduly burdensome. To address this problem, tri-corporate managers have been trying to simplify the evaluative questionnaire for future use. With the next release of ***TRILLIUM***, due in October of 1993, it is hoped that these problems will be eradicated.

## *TRILLIUM* and Its Reuse Criteria Enjoy Strong Support (4 of 4)

***Supplier Support is Demonstrated by Customer and In-house Training***

- **All NT staff attend a course on quality**
- **NT trained 90 staff as in-house assessors**
- **For Bell, qualifications include extensive field experience and knowledge of SEI/CMM, *TRILLIUM* and quality**

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NOTES:

Supplier Support for ***TRILLIUM*** Is Demonstrated by Customer and In-House Training

NT training programs are indicative of supplier support for ***TRILLIUM***. They train customers (other than Bell) who do not have the necessary expertise to participate in the assessment process. NT also has internal programs, through which they have trained approximately ninety people to date as in-house assessors.

NT makes this effort because competent ***TRILLIUM*** assessors greatly contribute to the gains from the model. In an assessment, the right team of experts will interpret practices in the model to the best advantage of the supplier organization. Inexperienced people, however, will simply check yes or no when answering the questionnaire, which detracts from the value of the exercise.

According to an experienced Bell assessor, representing the customer in supplier audits and self-assessments requires extensive experience in the technical domain, a knowledge of quality, a working knowledge of the ***TRILLIUM*** and SEI models, and excellent management skills. Before starting, assessors should gather information on the targeted organization's software products. They should also keep a developer's perspective by remaining connected to the software field (keeping their software development skills up to date).

## Impact of *TRILLIUM* and Reuse Criteria is Promising

- ***TRILLIUM*** **is key for long-term Tri-corporate success**
- **Reuse practices have a positive impact**
- **Expansion of reuse practices looks promising**
- ***TRILLIUM*** **expanding to external suppliers, Canadian and French Governments, ISO (SPICE)**
  - **External MIS suppliers**
  - **Weapons Systems — French MOD**

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NOTES:

THE IMPACT OF *TRILLIUM* AND ITS REUSE CRITERIA IS PROMISING

For Bell, there is preliminary data which indicate a substantial positive impact from ***TRILLIUM*** in terms of supplier performance. Although competitive gains in these organizations have been attributed to many additional factors by tri-corporate managers, NT and BNR acclaim the success of ***TRILLIUM***. For example, the most recent surge in growth, concurrent with the implementation of ***TRILLIUM***, has been attributed to the globalization of operations. At the same time, ***TRILLIUM*** has been cited by these individuals as an essential element in ensuring long-term tri-corporate growth.

Reaction to the reuse criteria within the model is also positive. According to the Manager of Transmission Development Processes, ***TRILLIUM*** requirements have attempted to formalize pre-existing reuse practices and will help to promote reuse within the tri-corporate organizations. This statement is corroborated by other tri-corporate managers. The impact of ***TRILLIUM's*** reuse practices, however, has not yet been measured and is difficult to separate from the pre-existing reuse practices.

*TRILLIUM* Is Described as Key to Tri-Corporate Success.

Tri-corporate managers stated that ***TRILLIUM*** is viewed as a means of promoting future growth and quality. While it is too early to measure conclusively, Coallier states that participants in initial pilots appear to be more user focused, responsive to customer needs, and products are generally more stable. Management at supplier organizations, NT and BNR, stated that they view the model as a means of achieving aggressive corporate goals. They further stated that ***TRILLIUM*** will have a greater future impact, when they have implemented the practices at higher levels of the model. This will be especially important as they expand into the global market.

From a different perspective, Professor Pierre Robillard at Ecole Polytechnique stated that ***TRILLIUM*** has been effective in identifying weaknesses in, and providing structure to, the development process in his organization. However, he did have criticisms of the model. He stated that ***TRILLIUM*** stresses process over product, a point that his organization is currently studying, and he said that some ***TRILLIUM*** practices

are not relevant for small development organizations. In his view, the latter is particularly true of the higher level practices in the model, which may not be worth achieving on the basis of cost/benefit analysis.

Reuse Practices in *TRILLIUM* Are Viewed as Having a Positive Impact

Reuse was cited by a number of interviewees as being an essential part of any large scale, modern software development process. Reuse was also cited as a major success factor for tri-corporate systems. While we were not able to obtain documentary evidence, in recent years, there has been a shift in the way reuse is practiced in tri-corporate organizations that may result from ***TRILLIUM***. NT and BNR have placed greater emphasis on the infrastructure required for effective reuse. They are measuring the long-term benefits of creating this infrastructure and are rewarding developers for producing reusable modules, regardless of the short-term earning potential of this work. In fact, according to the Director of Synergy Architecture, success in developing reusable products is now more highly valued than producing code with potential for only short-term profits. Further, greater emphasis has been placed on managing the development process.

Expansion of Reuse Practices in *TRILLIUM* Looks Promising

While several major product lines, such as switching and transmission systems, incorporate advanced reuse practices, only a small set of reuse practices are presently used throughout all tri-corporate development projects. This is a function of the limits of reuse knowledge and the difficulty in implementing new ideas. In general, reuse practices that are developed don't easily get into "street practice" in the tri-corporate because the requisite infrastructure for serious reuse only exists in pockets. NT and BNR have been working to develop this infrastructure with the help of the ***TRILLIUM*** model. At this stage, many of the level 4 and 5 ***TRILLIUM*** reuse practices are projections which look promising for future use when technology exists to support them. For now, NT and BNR use only those practices that are clearly defined and yield a measurable benefit.

*TRILLIUM* Is Expanding to External Suppliers and to Other Domestic and International Organizations

Aside from self-assessments in the above mentioned organizations, there have been a number of supplier audits outside the tri-corporate family, and there is growing momentum to expand use of the model to assess external suppliers of management information systems. Additionally, ***TRILLIUM*** is expanding rapidly to other domestic and international organizations, such as the International Standards Organization (ISO)[15] and the Canadian and French governments.

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15 ISO is working on a Software Process Improvement and Capability dEtermination (SPICE) project, code numbered JTC1/SC7/WG10. The objective of the SPICE project is to develop an international standard on Software Process Assessment.

## Similarities and Differences Provide Perspective

- ***TRILLIUM*** **Reuse Practices May Be Relevant to DoD**
- **Differences Provide Perspective for Future Strategies**

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NOTES:

SIMILARITIES AND DIFFERENCES PROVIDE PERSPECTIVE

There are a number of similarities and differences between DoD and Bell in the acquisition and development of software. The similarities stem from the common requirements of large, complex software systems that are cost effective and assure high quality. The differences exist primarily because of the distinctions in relationships between Bell and its suppliers and DoD and its suppliers. We believe that the areas in which Bell and DoD exhibit similarities are primarily constants which are necessary for effective reuse and strongly support the relevance of this case study for DoD. Further, dissimilarities, which now exist, are variables which may serve to clarify future DoD reuse strategies.

## Similarities and Differences Provide Perspective
(1 of 2)

*Technical*

**Similarities:**

- **Both DoD and Bell require large, complex, critical systems that must quickly adapt to new requirements**
- **Both DoD and Bell benefit from COTS products and industry standards**

**Differences:**

| *Bell / Suppliers* | *DoD / Suppliers* |
|---|---|
| BNR has built, controlled and used proprietary development and target environments | DoD has had less success, e.g., ALS (Ada Language System) |
| BNR's primary reuse experiences involve commercial telecommunications, where common, exact architecture and interface standards are the norm | DoD deals with an array of domains, few have this level of industry-wide definition and coherence |

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## Similarities and Differences Provide Perspective
(2 of 2)

### *Organizational and Regulatory*

| *Bell / Suppliers* | *DoD / Suppliers* |
|---|---|
| **Tri-corporate acquisition policies reflect developing and advancing cooperative relationships with suppliers, with the end goal of improving product quality** | **Cooperative relationships, with synergistic participation among Govt customers and contractors, can and do work, but they are not the norm**<br>*Relationships between DoD and suppliers are often characterized as antagonistic*<br>*Formal, cooperative relationships, e.g., FFRDCs, CRADAs are not mainline supply vehicles* |
| **A single, unified Bell organization assesses and promotes quality for both hardware and software** | **DoD is not so centralized** |
| **Bell purchases most telecom products from one vendor** | **Many large DoD projects involve multiple vendors each with one or more cultures, development environments, standards, etc.** |
| **Suppliers meet Bell's requirements and remarket systems on the international market** | **Dual use is not so prevalent for DoD suppliers** |
| **National security is not an issue** | **National security is an issue** |

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NOTES:

Lessons Learned from ***TRILLIUM*** Are Relevant for DoD

Bell and DoD require large, complex systems with similar reliability standards and real-time response requirements. Like Bell's systems, many new DoD systems are written in a common, modular, high-order language. Moreover, in the telecommunications industry and in defense systems, many products have well-defined domains and long life cycles. As noted earlier in the study, these characteristics promote effective reuse practices such as those found in ***TRILLIUM***. Furthermore, as previously described, Bell and DoD suppliers are, to a degree, similarly motivated by the predominant influence of their largest customers (i.e., DoD and Bell).

Because of the successes attributed to ***TRILLIUM*** and its reuse standards by tri-corporate managers, we believe that the similarities in software acquisition and development between Bell and DoD warrant further consideration of ***TRILLIUM*** by DoD.

Differences Provide Perspective for Future Strategies

Despite the influence that Bell and DoD can exercise over their suppliers, there are major differences in organizational culture and approach to suppliers between these organizations. For example, the relationships between tri-corporate organizations (customers and suppliers) are much closer than those between DoD and its contractors, which tend to be more formal. Bell strives to build strong, mutually beneficial relationships with suppliers. They emphasize the link between the quality of suppliers' products and the quality of their own products, and use ***TRILLIUM*** assessments to strengthen supplier software development performance. This will, in turn, have positive repercussions for their own systems.

Conversely, "arms length," and in some cases, adversarial relationships, exist between the DoD and its suppliers. This can be an impediment to using a program like ***TRILLIUM***. According to Bell managers, ***TRILLIUM*** requires partnering of customers and suppliers to achieve the full benefits of the model. ***TRILLIUM's*** greatest impact is in helping suppliers develop better software development practices through assessments, not in auditing these practices and setting arbitrary standards.

Based on this information, we believe that an environment of cooperation is necessary to effectively implement practices or to adapt ***TRILLIUM*** or a similar model for DoD purposes. If cooperative relationships cannot be developed between DoD and its suppliers and the model is instead imposed on suppliers, it may inhibit the potential opportunities and benefits associated with a successful application of reuse in the ***TRILLIUM*** model.

Other major difference between Bell and DoD exist in standards for software architecture and regulations in the defense and telecommunications industries. The telecommunications industry is advantaged by the presence of industry-wide standards such as Bellcore TR303 and TR308, which are consensual and unambiguous. Bellcore defines industry standards for software architecture, and suppliers work to meet these standards. In contrast, the defense contracting industry deals with a vast array of systems, most of which do not have well-defined, shared architectures. Further, telecommunications firms are not bound by stringent procurement and other government regulations that exist in the defense contracting industry.

Moreover, Bell and DoD supplier market situations differ. NT and BNR do not deliver custom-built software to Bell for its large switch software. They deliver the same products to other large commercial clients, and realize that ***TRILLIUM*** has the potential to facilitate competitive gains in all markets. Many DoD suppliers, however, develop products exclusively for DoD according to specifications. In this situation, there is less incentive for suppliers to implement a reuse practice like ***TRILLIUM***, as it will not help their competitive situation in other markets. We believe, however, that with the impending conversion to commercial applications of DoD supplier technology (dual-use technology),[16] this discrepancy may soon begin to be ameliorated. Under this condition, a model like ***TRILLIUM***, containing reuse criteria, could assist in stimulating the conversion process.

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16 DoD and a number of other Federal agencies have developed a government-wide program to focus on technologies of critical importance to both national security and the national economy.

# Conclusions

*Key Factors Contributing to Reuse Success*

- **Assimilating reuse criteria into a capability assessment model and total quality management process**
- **Providing an atmosphere of participatory management within a defined and controlled group of suppliers and users**
- **Selecting projects that have characteristics (large, complex systems with stable, well-defined domains and long life cycles) conducive to securing the benefits of reuse**
- **Using proper development, analysis, architecture, tools and techniques in a reuse-oriented management structure**
- **Adapting reuse approaches to meet evolving needs**

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NOTES:

Conclusions

Bell developed and implemented ***TRILLIUM*** and its reuse practices within a close supplier network. This gave them a level of cooperation and trust that may be difficult to develop widely for DoD and its contractors. *Nevertheless,* reuse practices in conjunction with a defined quality control process is considered by tri-corporate managers to be a major factor in developing better quality software systems at less cost.

In our view, the key reuse factors contributing to this success are:

- assimilating reuse criteria into a capability assessment model and total quality management process
- providing an atmosphere of participatory management within a defined and controlled group of suppliers and users
- selecting projects that have characteristics (large, complex systems with stable, well-defined domains and long life cycles) conducive to securing the benefits of reuse
- using proper development, analysis, architecture, tools and techniques in a reuse-oriented management structure
- adapting reuse approaches to meet evolving needs

# *TRILLIUM* CASE STUDY APPENDICES

## APPENDIX I: Major contributors to the case study

| | |
|---|---|
| Coallier, Francois | Associate Director of Quality Engineering & Research for Bell Canada. Bell principal author of *TRILLIUM*. |
| Drouin, Jean Normand | Advisor for Quality Engineering for Bell Canada. Drouin has extensive experience with *TRILLIUM* audits and assessments. |
| Ficici, Mehmet | Director of Corporate Quality for Northern Telecom and *TRILLIUM* author. |
| Fraser, Steven | Software Reuse Program Manager for Bell Northern Research. Expert in the field of software reuse and the architect of the reuse practices in *TRILLIUM*. |
| Gammage, Neil | Director of Synergy Architecture for Bell Northern Research. BNR principal author of *TRILLIUM*. |
| Graydon, Allan | Manager of Software Excellence at Northern Telecom. NT principal author of *TRILLIUM*. |
| Joyce, Don | Manager of Transmissions Operations at Bell Northern Research. Responsible for transmissions systems operations and champion and author of *TRILLIUM* at BNR. |
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| Robillard, Pierre | Professor and Program Director for software development organization at Ecole Polytechnique. Has used *TRILLIUM* for assessments at his organization. |

## APPENDIX II: List of Reviewers

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## APPENDIX III: Source Documents


*Advances in Software Reuse, Selected Papers from the Second International Workshop on Software Reusability, Proceedings;* IEEE Computer Society Press; Los Alamitos, CA; 1993

*Annual Report;* BCE Incorporated, 1992

*Annual Report;* Bell Canada, 1992

*Annual Report;* Northern Telecom Limited, 1992

*Bell Canada Document,* Draft 2.2, "*TRILLIUM*: Telecom Software Product Development Capability Assessment Model," July 1992

*Business Week,* "What Really Happened at Northern Telecom," August 9, 1993

*Case Study Evaluations;* U.S. General Accounting Office, Program Evaluation and Methodology Division; November 1990

*Capability and Commitment Report;* Bell Canada, 1989

*Capability Maturity Model;* Software Engineering Institute, Carnegie Mellon University; Reference Number, CMU/SEI-91-TR-24

*DoD Software Reuse Initiative; Vision and Strategy;* Department of Defense, July 15, 1992

*Government Auditing Standards,* U.S. General Accounting Office, Comptroller General of the United States, 1988 Revision

Fraser, Steven; Saunders, Clifford; *Enhanced Reuse with Group Decision Support Systems;* Bell Northern Research Ltd. Tandem Communications Inc.

Ficici, Mehmet; *Excellence, Software Process Self-Assessment, Team TRILLIUM;* Northern Telecom, Bell Northern Research, and Bell Canada; presentation to the QMAC Workshop, May, 1993

*Northern Telecom news release,* July 21, 1993

Paulk, Mark; *Identifying Resources for the SPICE Project;* Software Engineering Institute, Carnegie Mellon University; March 24, 1993

Pitcher, Mari; *QMAC Technology Transfer presentation;* AVP Manufacturing, Northern Telecom, May 4, 1993

Russell, Wayne; *SEI Influence at GTE;* presentation

*SOFTWARE REUSE: Major Issues Need To Be Resolved Before Benefits Can Be Achieved;* U.S. General Accounting Office; Washington, D.C.; January, 1993

*Telesis,* Volume 16, Number 3; Bell Northern Research; 1989

*Telesis,* Issue Number 92; Bell Northern Research; 1991

*TRILLIUM- Telecom Software Product Development Capability Assessment Model;* Bell Canada; July 1992

## APPENDIX IV: List of Acronyms/Abbreviations

ACM/SIGAda (Association for Computing Machinery/Special Interest Group on Ada)
AE (Applied Expertise, Inc.)
ALS (Ada Language System)
ARPA (Advanced Research Project Agency, DoD)
ASQC (American Society of Quality Control)
Bell (Bell Canada)
BNR (Bell Northern Research)
CM (Configuration Management)
CMM (Capability Maturity Model, by SEI)
COS (Central Office Switching)
COTS (Commercial Off-the-Shelf)
CRADA (Cooperative Research and Development Agreement)
DMS (a product line of Northern Telecom digital switching systems)
DoD (U.S. Department of Defense)
FFRDC (Federally-Funded R&D Center)
GAO (U.S. General Accounting Office)
IEEE (Institute for Electrical and Electronics Engineers)
ISO (International Standards Organization)
LOC (Lines of Code)
MIS (Management Information Services)
MLOC (Million Lines of Code)
MoD (Ministry of Defense, French)
NASA (National Aeronautic and Space Administration)
NT (Northern Telecom)
QMAC (Quality Management Assurance Committee)
SEI (Software Engineering Institute, sponsored by DoD)
SSE (Space Station Software Environment)
STARS (Software Technology for Adaptable, Reliable Systems, DoD)
S/W (software)
TQM (Total Quality Management)
*TRILLIUM* — Telecom Software Product Development Capability Assessment Model
V&V (Verification and Validation)

## APPENDIX V: *TRILLIUM* Index

(See Attached Sheets)

Draft 2.2

July 1992

# TRILLIUM

## TELECOM SOFTWARE PRODUCT DEVELOPMENT CAPABILITY ASSESSMENT MODEL

## TABLE OF CONYENTS

6.5.2.7 A formal process is used to create and release line-ups [SEI SCM Activity 8].

6.5.2.8 A Software Configuration Management (SCM) organization/function exists for each project, responsible for creating and managing the software library for the project [SEI SCM Ability 2] [IEEE Std. 828 2.2] [Trillium].

6.5.2.9 Source code is under SCM control [Trillium] [Bellcore TR-TSY-000179 2.5.8 & 2.10.1.2].

**Level 3**

6.5.3.1 User requirements, specification documents, design documents, source code and test cases are under SCM control [SEI SPE Activity 11] [Bellcore TR-TSY-000179 2.10.1.1].

6.5.3.2 There is full forward and backward traceability between all configuration items (e.g design documents forward to code units, design documents backward to specification documents) [SEI SPE Activity 11] [Bellcore TR-TSY-000179 2.4.1] (Ref. IEEE Std. 1012).

**Level 4**

6.5.4.1 All development tools are under SCM control [Trillium].

**Level 5**

6.5.5.1 Development history (e.g. design decisions, design rationale) is captured and maintained under SCM control [Trillium].

## 6.6 Re-Use

**Level 2**

6.6.2.1 Cloning (i.e. copying and modifying) of existing software units in new designs is tracked [Trillium].

6.6.2.2 Tools are provided to aid propagation of changes from one software unit to cloned or cloned from units [Trillium].

6.6.2.3 A formal procedure for the selection, verification & validation and tracking of third-party software components is in place [Trillium] [ISO 9000-3 6.8].

**Level 3**

6.6.3.1 Pre-developed and certified source code templates are provided in a template library as a basis for cloning [Trillium].

6.6.3.2 Pre-developed and certified source code units are provided in a software component library [Trillium].

6.6.3.3 A component development function exists to develop, certify and maintain the items in the template and component library [Trillium].

6.6.3.4 Specific steps are included in the organization's standard software development process for the purpose of maximizing component re-use [Trillium].

6.6.3.5 Re-use of pre-developed components is measured, encouraged, and rewarded by the organization's reward system [Trillium].

**Level 4**

6.6.4.1 Pre-developed and certified designs are provided in a software component library for the use of developers [Trillium].

6.6.4.2 CASE tools are provided to support re-use of software components in new product developments [Trillium].

**Level 5**

6.6.5.1 Knowledge based CASE tools are provided to automate re-use of components in new product developments [Trillium].

### 6.7 Reliability Management

**Level 2**

6.7.2.1 System and service wide reliability and maintainability plans and objectives are established [Trillium] [IEC 300].

6.7.2.2 System Availability (unavailability) is defined at the product definition phase, including Failure Definition/Classification (Critical, major, minor) and Operational Modes Definition (non-stop, mission-oriented, batch,...) [Trillium] [IEC 300].

6.7.2.3 Software [Un] availability is apportioned at the product definition phase including S/W [Un]availability due to Enhancements (upgrades), S/W [Un]availability due to Failures and S/W Failure Intensity requirement definition per failure classes [Trillium].

6.7.2.4 The following data is collected and processed (Ref. IEEE Std. 982.1 & 982.2):

a) Test Log (Test Execution Time),

b) Failure Log,

c) Installation Date/Time Recording,

d) Cumulative Execution Time Logging per release,

e) Failure recording and classification,

f) Failure-related down time recording,

g) Enhancement-related down time recording.

## APPENDIX VI: Acknowledgments

Applied Expertise, Inc. (AE) wishes to acknowledge the participation and support of the people who helped to make completion of this case study possible. We would like to extend our appreciation to Francois Coallier and Jean Normand Drouin of Bell Canada, Allan Graydon and Mehmet Ficici of Northern Telecom, Neil Gammage, Steve Fraser, Don Joyce and Steve Ornburn of Bell Northern Research, and Professor Pierre Robillard and Denis Pomerleau of Ecole Polytechnique, all of whom participated in a number of face to face interviews and follow-up phone calls. We would also like to thank Mike Konrad of the Software Engineering Institute for providing information on the International Standards Organization (ISO) Software Process Improvement and Capability dEtermination (SPICE) project.

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